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Engineering Geological Investigation of a Proposed Construction Site Area of Adekunle Ajasin University Sport Complex, Akungba-Akoko, Southwestern Nigeria Using Electrical Resistivity

Adedibu S. Akingboye[1*], Opeyemi O. Aperolola[1], Richard O. Ijaleye[1]

[1*, 1]Department of Earth Sciences, AdekunleAjasin University, Akungba-Akoko, Nigeria

E-mail: akiingboye.a.sunny@gmail.com/adedibu.akingboye@aaua.edu.ng

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Abstract

Application of geophysical investigation which employed the use of Vertical Electrical Sounding (VES) at Adekunle Ajasin sport complex, Akungba-Akoko was undertaken for the purpose of engineering site characterization to determine the resistivity parameters to evaluate the near surface earth materials and its engineering implications, towards the construction of an engineering structure. Eight VES positions where occupied across the study area. Quantitative interpretation was initially carried out on the VES using the partial curve matching technique with WinResist software. Four lithologic units were delineated namely top soil, lateritic layer, weathered layer and fresh basement (Granite gneiss). The topsoil resistivity varied from 101-540Ωm and thickness ranged from 0.7and 5.3 m, composed of soil types such as clay, sandy clay and laterite. The weathered layer resistivity varied from29-782Ωm and thickness of 2.2-14.5 m, while the partial fractured basement ranged from 538-869 Ωm with thickness ranged from 4.9-12.5 m. Low resistivity zones, ridges and depressions were envisaged on the iso-resistivity and the isopach of the overburden thickness map respectively. The variation in resistivity values showed that the subsurface earth materials differ in their competency. Low resistivity (clay soil), laterally inhomogeneous subsurface layer and conductive zones identified as fractures and faults are possible source of failure. Hence, high rise building or structure with a strip footing foundation will require special engineering foundation such as pilling so that such building will rest directly on basement.

Keywords: Engineering structures, Akungba-Akoko, Resistivity sounding, Geoelectric parameters, Foundation.

Introduction

Detail understanding of the geoelectric properties of the subsurface earth material and its engineering implications is important in pre-construction foundation studies. Foundation investigation is an important program in designing and building economically sound and safe engineering structures. Several approaches have been used for the success of foundation investigations. Geophysical methods, particularly electrical resistivity technique, had been extensively used for a wide variety of engineering and environmental problems (Boyce and Kaseoglu, 1996; Olorunfemi et al., 2004; Nigm et al., 2008; Oyedele et al., 2009).

Geophysical methods have been found very relevant in construction of engineering structures due to its non-intrusive approach to civil engineering site investigation, relatively low cost and time saving advantage. Structural failure is said to have occurred when there are unacceptable differences between expected and observed performance of any structure. The cause could be from a natural cause relating to tectonic activities which takes place in the earth e.g. earthquake, tremor, faulting and folding; while it could also be as a result of clay content of the topsoil, heterogeneous nature of the sub-base and sub-grade materials, poor quality of building materials, old age of building, and failure precipitated by differential settlement, differences in expansion and compression coefficients of construction materials, relative changes in the shapes and sizes of saturated soilsand errors in structural design (Oladapo, 1997, Ofomola et al., 2011, Oyedele and Olorode, 2011, Lateef and Adegoke, 2011, Egwuonwu and Sule, 2012, Adelusi et al., 2013).

The incompetent earth layers could be related to differential settlement, fractures, faults, joints and lineaments structures underlying the construction site. Understanding the subsurface geology prior to construction will therefore provide the required information to prevent structural failure. When the foundation of an engineering structure is erected on less competent earth layer, it poses serious threat to the structure and can also lead to its collapse. Thus, need to evaluate the subsoil integrity, suitability and competency prior to construction. The durability and safety of engineering structural setting depend on the characteristic of the subsurface earth materials and the mechanical properties of the overburden. Pre-construction foundation studies will reveal potential future subsurface problems and assist in providing possible solutionsbefore erecting a building. Such result will serve as baseline information which is invaluable (Yusuf et al., 2015).

This paper presents the result of a study on subsurface geological investigation to characterize its engineering geological properties to infer their suitability and pinpointing favourable area to serve as a foundation for erecting structure on it using vertical electrical sounding.

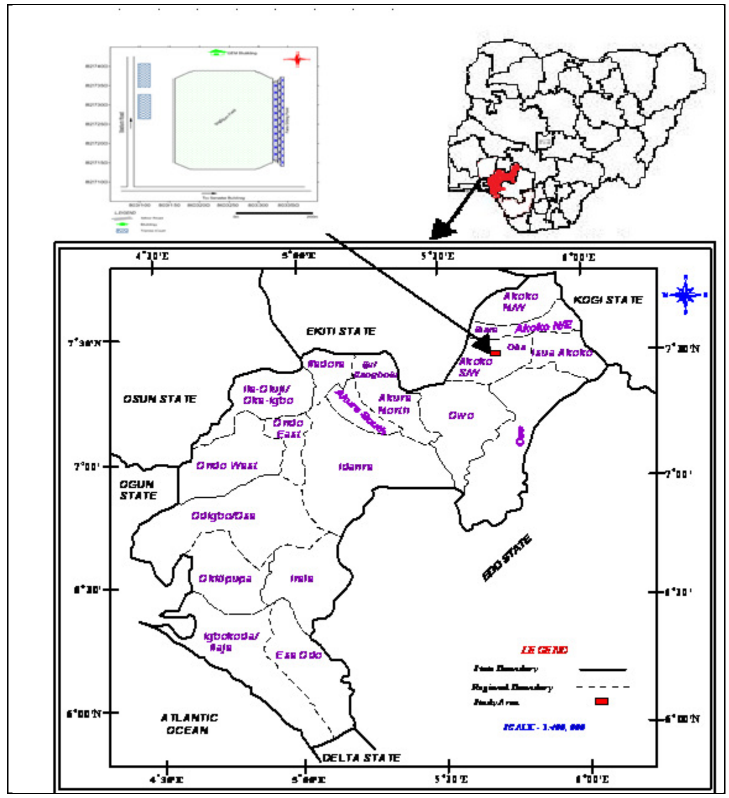

Fig. 1. Map of Ondo State showing the Study Area and the Layout

Description of the Study Area

The study area is located in Akungba-Akoko, Ondo State, Southwestern Nigeria (Fig. 1). It is confined within approximate northing and easting of 825739 m N and 802713 m N and 801047 m E and 824429 m E the expressed in the Universal Traverse Mercator (UTM) Minna Zone 31 coordinates respectively.

The area is accessible through secondary roads from Ikare in the North and Owo in the South. The physiographic disposition of the area consists of a gently sloping central low lying region surrounded in a perimeter-like fashion by high rising granitic hills to the north, west and south-east. Topographic relief is

generally greater than 345 m above sea level with perimeter hills rising up to 420 m above sea level.

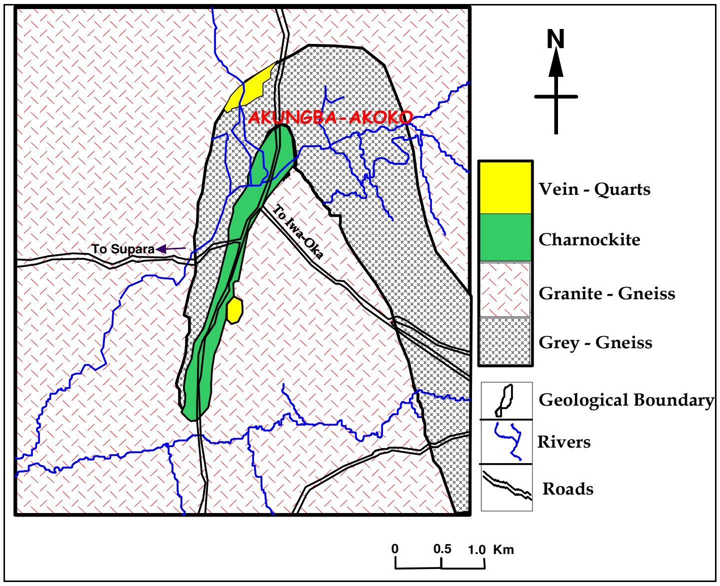

Fig. 2. Geologic Map of Akungba – Akoko and its environs.

The area is underlain by rocks of the migmatite-gneiss complex of the basement rocks of the south-western Nigeria (Rahaman, 1989). Specifically, the suite of rocks consists of biotite-rich grey gneiss, granite gneiss and lesser amounts of charnockites (Figure 2). The grey gneiss rock type is commonly prominent and widely distributed in the area. Its colour varies from light to dark grey and it is usually of medium to coarse grained with phaneritic texture. This rock contains mineralogical banding of quartz, feldspar, biotite and sometimes garnets. Granite gneiss is foliated, mineralogically it contains quartz, feldspar, and biotite with intrusions of pegmatite and quartz feldspathic veins. The charnockiteis a pyroxene bearing granite with dark greenish colour and occur as boulders with a weak foliation and usually coarsely grained. It is an intrusive migmatite rock, which shows granuloblastic texture.

The area is drained by few seasonal streams which generally take their course from high reliefs in the northeast. Regolith development in the area is apparently thin. This is appreciated from visual reconnaissance evaluation of the area; the fresh basement rocks frequently outcrops at short intervals in several parts of the area. As other rocks of the Precambrian basement complex of south-western Nigeria, the rocks of the Akungba-Akoko area have undergone at least two episodes of tectonic deformation. It is fairly well drained with rivers which are seasonal and which form minor tributaries of the main rivers.

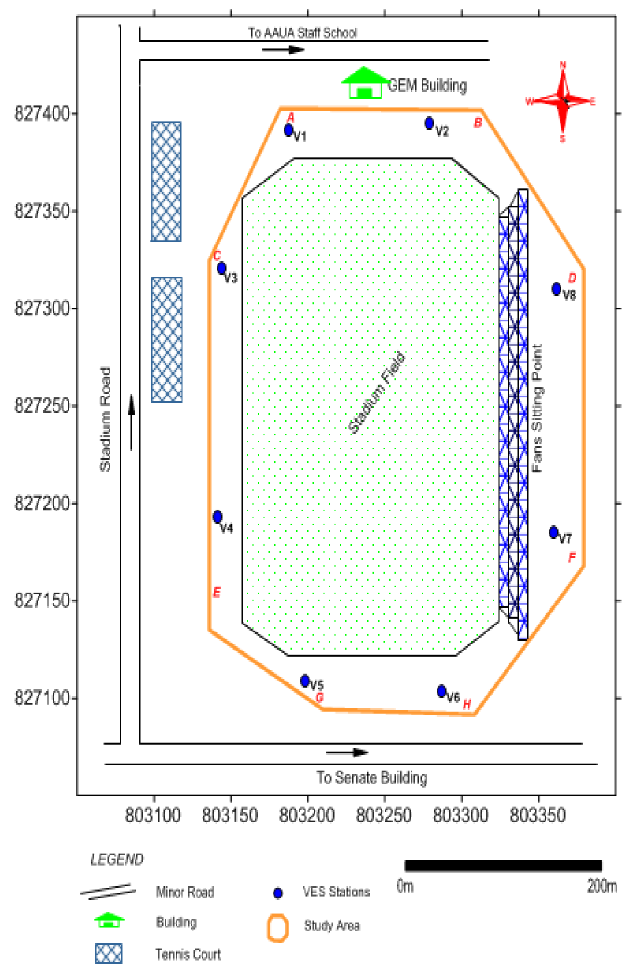

Fig. 3. Data Acquisition Map of the Study Area.

Methodology

Field Survey/Data Acquisition Technique/Data Processing

Vertical Electrical Sounding (VES) using the Schlumberger electrode configuration was carried out at eight (8) selected points within the study area

(Figure 3). In all, eight (8) VES points were located and fully occupied within the study area covering expected areas that buildings could be sited on around the stadium. The ABEM SAS 1000 Resistivity Meter was used for the measurement of the ground resistivity.

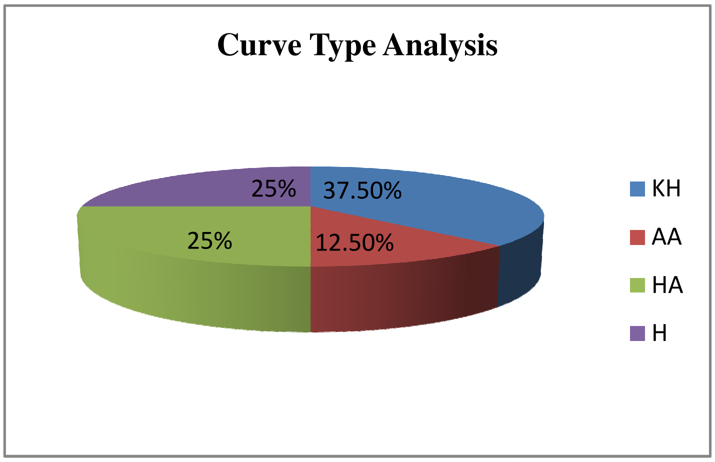

Fig. 4. Frequency distribution chart of curve types.

The VES data obtained were subjected to partial curve matching using two-layer master curves and auxiliary curves as an initial stage of data interpretation (Orellana and Mooney, 1966). The geoelectric parameters obtained from the partial curve matching were refined by computer iteration technique using WinRESIST software (Vander Velpen, 1988). The interpretation by forward and inverse modelling techniques was an interactive computer graphic display system (Ghosh, 1971; Sharma, 2000). The system made use of a fast computer to calculate an apparent resistivity curve for a given layer sequence. From the above, the refinement of the results of the partial curve matching interpretation was obtained and found satisfactory with the root square mean (rsm) of less than 10 %. The final interpreted results were used for the preparation of geo-electric sections and also the acquired data were presented as, frequency distribution chart, tables, depth sounding curves and maps.

Results and Discussions

Table 1 shows the summary of the VES results in terms of the geoelectric properties of the study area, these parameters were used to prepare geoelectric sections and subsurface maps such as iso-resistivity map and iso-pach map. The generated curves after modelling are also shown.

Depth Sounding Curve Types

It could be observed that the KH-type curve is the most dominant (Figure 4); accounting for 37.5%, while type H and HA accounting for 25% each, of the curve type respectively, being indicative of shallow resistive bedrock. Type AA accounts for 12.5%, this may typify rapid resistivity progression possibilities. Approximately 25% of the soundings are 3-layered while the other 75% are 4-layered. According to Olorunfemi and Olorunniwo (1985), it is possible to classify the curve types into four distinct classes as follows: class 1 type curves, class 2 type curves, class 3 type curves, and class 4 type curves.

Class 1 type curve, represents a subsurface condition in which there is an increase in resistivity values from the topsoil to the basement rock, example is the A-type curve. In class 2 curve types, the upper horizons when not leached are usually clayey and of low resistivity, immediately underlying this layer (usually low resistivity, high porosity, low specific yield and low permeability aquiferous zone) is the fresh basement. This classic architecture of the profile produces an H-type curve signature, which is found to be most prominent in the area.

Curve types of class 3 are typical of a succession of relatively low and high resistivity layers. The K type is found where a highly resistive lateritic layer underlies low resistivity clayey topsoil and weathered zone in turn underlies the former. Or it may result from where the basement, fractured at depth, underlies the topsoil. In the curve type in class 4, the succession of the subsurface layers starts with a highly resistive topsoil followed by a more conductive horizon and

Table 1: Summary of the VES Quantitative Interpretation Results.

VES Station	Curve Types	Apparent Resistivity (Ωm)	Thickness (m)	Depth (m)	RMS Error	Layer Description
1	KH	101	1.0	1.0	10.0	Topsoil
		513	2.2	3.2		Laterite
		142	16.7	20.0		Weathered Layer
		4166	-	-		Fresh Basement
2	H	246	1.7	1.7	9.4	Topsoil
		29	3.0	4.7		Weathered Layer
		15658	-	-		Fresh Basement
3	KH	219	5.3	5.3	4.0	Topsoil
		1540	12.7	18.0		Laterite
		869	10.8	28.8		Weathered Layer
		4328	-	-		Fresh Basement
4	HA	540	2.2	2.2	2.2	Topsoil
		328	5.9	8.0		Weathered Layer
		538	12.5	20.5		Fractured Basement
		1862	-	-		Fresh Basement
5	AA	148	2.7	2.7	4.7	Topsoil
		215	6.5	9.2		Weathered Layer
		782	4.9	14.1		Fractured Basement
		2619	-	-		Fresh Basement
6	H	249	1.4	1.4	2.5	Topsoil
		60	4.9	6.3		Weathered Layer
		13046	-	-		Fresh Basement
7	KH	231	5.3	5.3	3.8	Topsoil
		1479	14.5	19.8		Laterite
		564	14.1	33.9		Weathered Layer
		7169	-	-		Fresh Basement
8	HA	405	0.7	0.7	2.4	Topsoil
		203	2.5	3.2		Weathered Layer
		2615	18.6	21.8		Fresh Basement
		6739	-	-		Fresh Basement

then another less conductive layer underlies the latter example is the HKH-type curve.

Geo-electric Sections and Lithological characteristics

Five geoelectric sections were drawn in the N-S and approximately W-E directions within the study area along lines AB, CE, DF, GH, EG {Figure 3}.The VES interpretation results were used to prepare geoelectric sections displayed in Figure 5{a, b, c, d, e}. The geoelectric sections were constructed based on distribution of VES points in the survey area. The sections give an insight into the structural deposition of subsurface geologic units. The geoelectric sections delineated maximum of four geoelectric subsurface layers comprising the topsoil, weathered layer (gneissic rock), partly weathered/fractured basement and fresh basement (granite gneiss).

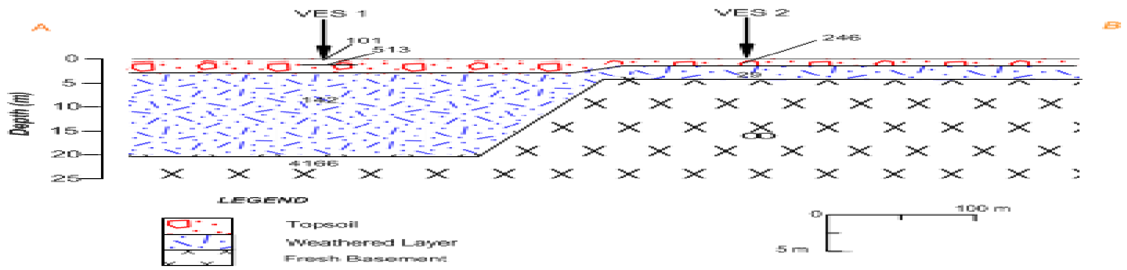

Fig. 5a. Geoelectric section along W-E Direction.

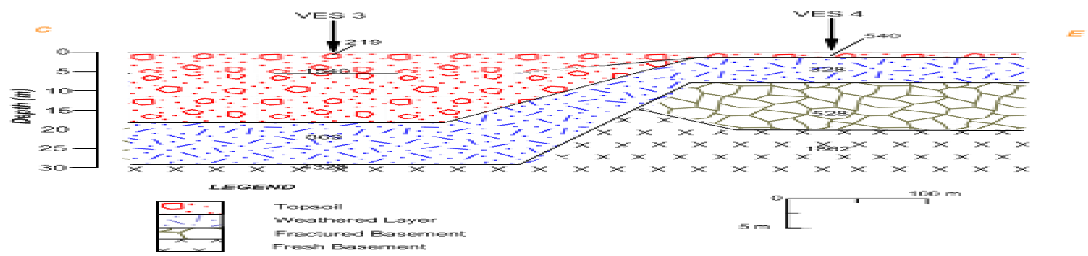

Fig. 5b. Geoelectric section along N-S Direction.

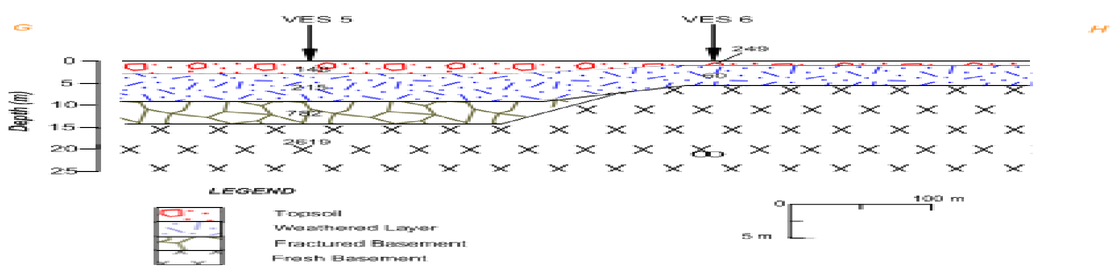

Fig. 5c. Geoelectric section along W-E Direction

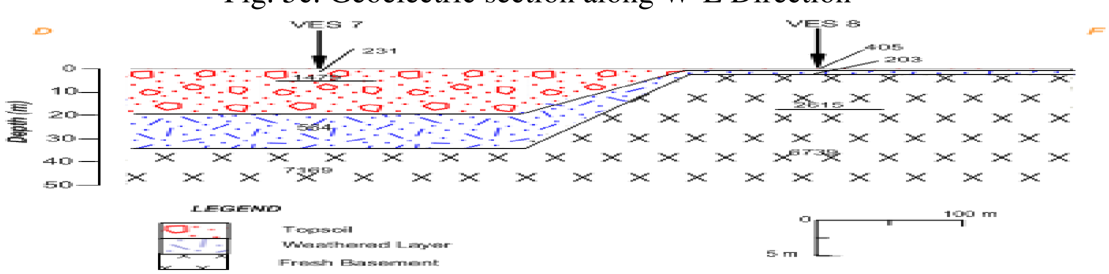

Fig. 5d. Geoelectric section along N-S Direction.

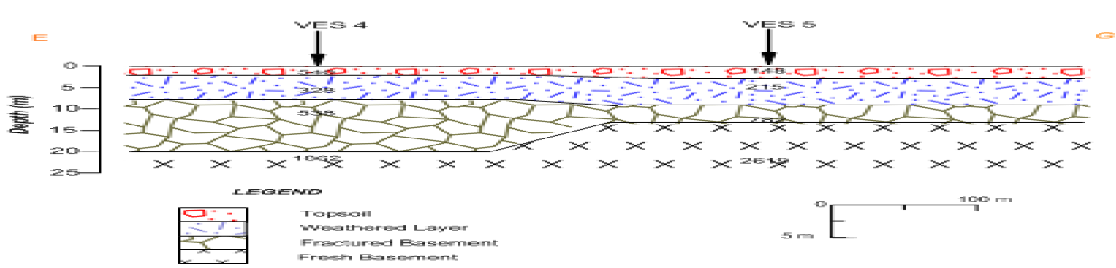

Fig. 5e. Geoelectric section along NE-SW Direction.

The resistivity of the first layer (topsoil) ranges from 101-540 Ωm and thickness ranging from 0.7-5.3 m. The topsoil is composed of soil types such as clay, sandy clay and laterite. The resistivity of the underlying layer (weathered layer), the resistivity varies from 29-782 Ωm and thickness varies 2.2-14.5 m. It is composed of clay, sandy clay and rock fragments. The weathered layer is underlain by the fresh basement but shows fractures in some places. The resistivity of the fractured zones varies between 538 and 869 Ωm and the thickness ranges from 4.9-12.5 m. The bedrock resistivity varies from 1862 to infinity and the depth to the bedrock ranges from 3.2-33.9 m. The geoelectric sections show that the overburden is averagely thick.

Geoelectric Section along W-E Direction

Two geoelectric profile trending west to east direction with length of about 100 m along lines A-B and G-H comprising of VES 1 and 2, and VES 5 and 6 respectively (figure 5a and 5c). A total of three to four geoelectric layers were delineated.

Along line A-B for VES 1 and VES 2 (figure 5a), three layers were delineated, the topsoil constitutes the first layer with resistivity ranging from 101to 246 Ωm, indicating that the topsoil is mainly sandy clay, with thickness range of 1.0 to 1.7 m. Underlying this layer below VES 1 is a lateritic layer with resistivity of 512 Ωm and a thickness of 2.2 m. The weathered layer is the second layer having resistivity range of 29 to 142 Ωm and thickness of 3.0 to 16.7 m; the highest thickness is around VES 1. The last layer is fresh basement and it is restricted beneath VES 2 and extends toward VES 1 appearing to be thin having resistivity values ranging from 4166 Ωm to ∞.

Along line G-H for VES 5 and VES 6 (figure 5c), four layers were delineated, the topsoil constitutes the first layer with resistivity ranging from 148 to 231 Ωm, with thickness range of 1.4 to 2.7 m. The weathered layer is the second layer having resistivity range of 60 to 215 Ωm and thickness of 4.6 to 6.5 m; the highest thickness is around VES 5, the low resistivity value in VES 6 is an indication of a weathered/fractured rock saturated with water. The fractured basement is the third layer and it is restricted beneath VES 5 with or no indication in VES 6, the resistivity is 782 Ωm with thickness of 4.9 m. The last layer is the fresh basement and the resistivity varies from 2619 Ωm to ∞.

Geoelectric Section along N-S Direction.

The two other geoelectric profile is oriented from north to south along lines C-E and D-F, this comprises of VES 3 and 4, and VES 7 and 8 respectively, with approximate length of about 100 m (figure 5b and 5d).

Along line C-E for VES 3 and VES 4 (figure 5c), four layers were delineated Four lithologic units were also delineated, the first layer being the topsoil has resistivity value of 219 to 540 Ωm and thickness of 2.2 to 5.3 m, the topsoil constitutes sandy clay, clayey sand and lateritic clay beneath VES 3 with very high resistivity and highest thickness envisage at VES 3. The second layer is the weathered layer with resistivity of 328 to 869Ωm and thickness range of 5.9 to10.8 m. The fractured basement is the third layer, the resistivity is 538Ωm with thickness of 12.5 m only for VES 4. The partial fractured basement is shown to have a low resistivity value, and this is due to infill geologic material or water saturation. Beyond this layer is the fresh basement complex with resistivity ranging from 1862Ωm to ∞.

Along line D-F for VES 7 and VES 8 (figure 5d), four layers were delineated the top layer resistivity ranges from 231 to 405 Ωm, indicating that the topsoil is mainly sandy clay, with thickness range of 0.7 to 14.5 m, the topsoil thin-out towards VES 8 where the weathered layer is almost close to the surface. The weathered layer which is the second layer has resistivity of 203 to 564 Ωm with thickness of 2.5 to 14.1 m, the weathered layer thin-out towards VES 8

because of the plunging of the outcropping basement under the topsoil. The basement is the last layer with resistivity ranging from 2615Ωm to ∞ with thickness of 18.6m to ∞.

Iso-resistivity and Iso-pach Map of the Topsoil

The iso-resistivity and iso-pach map of the topsoil of the survey is shown in Figure 6a and 6b respectively. This map shows the variation in the resistivity and thickness of the topsoil within the study area. It shows that the topsoil resistivity varies from 101 to 540 Ωm (which is typical of clay to hard-pan laterite). The resistivity is moderately high (between 200 and 500 Ωm) in the central part of the area particularly at the ENE and SWS parts. The resistivity of the topsoil is generally low within the study area (< 200 Ωm) which covers low portion in the south, and north-western portion of the area and the thickness for the topsoil varies between 0.5 to 5.4 m. This generally indicates that the topsoil in the area rarely goes beyond 1 m thickness for areas with <200 Ωm.

Iso-resistivity and Iso-pach Map of the Weathered Layer

The iso-resistivity and iso-pach maps of the weathered layer are shown in Figure 7a and 7b respectively. This Iso-resistivity and iso-pach maps of weathered layer show the distribution in the resistivities and thicknesses of weathered bedrocks (Granite-gneiss) within the study area respectively. The competency of the bedrock is a direct function of its hardness, that is, in-situ properties undeformed. Areas with intense weathered bedrock majorly caused by fluid occupying the pore spaces, fractures (joints and faults) thereby disengaging the crystal lattices of the rock and rendering it less competent for buildings without reinforce foundation. The thickness of the weathered bedrock poses risk to the buildings erected on such. The thickness of weathered bedrocks varies due to the undulating and irregular thicknesses of bedrocks. Weathered bedrock with low thickness tends to be competent than its counterpart with appreciably high thickness.

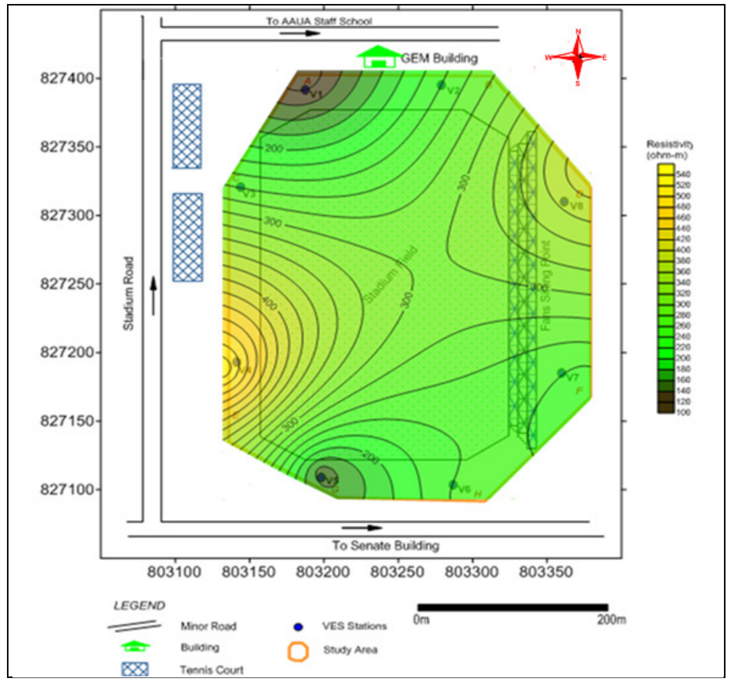

Fig. 6a. Iso-resistivity Map of the Topsoil of the Study Area.

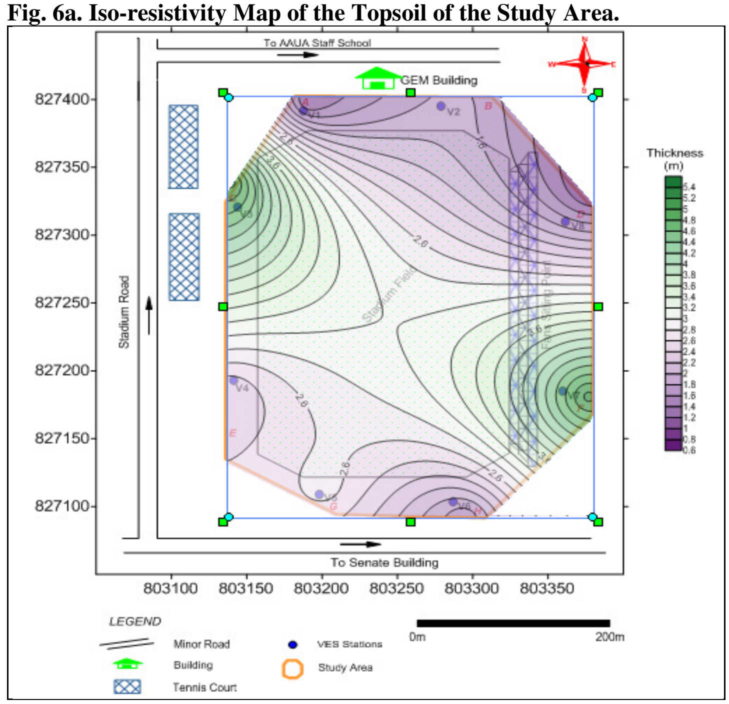

Fig. 6b. Iso-pach Map of Topsoil of the Study Area.

The iso-resistivity shows that the weathered layer resistivity varies from 29 to greater than 800 ohm-m. The resistivity of the weathered layer is considerably

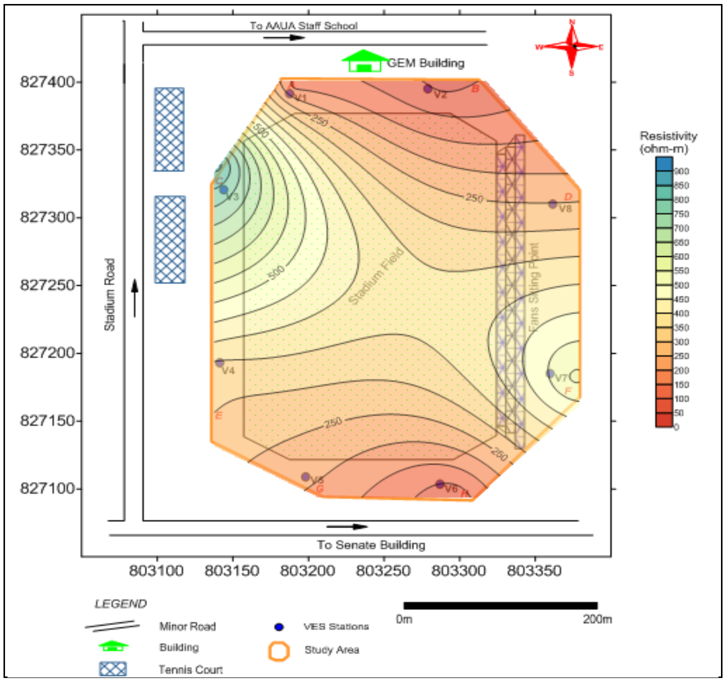

Fig. 7a. Iso-resistivity Map of the Weathered Layer of the Study Area.

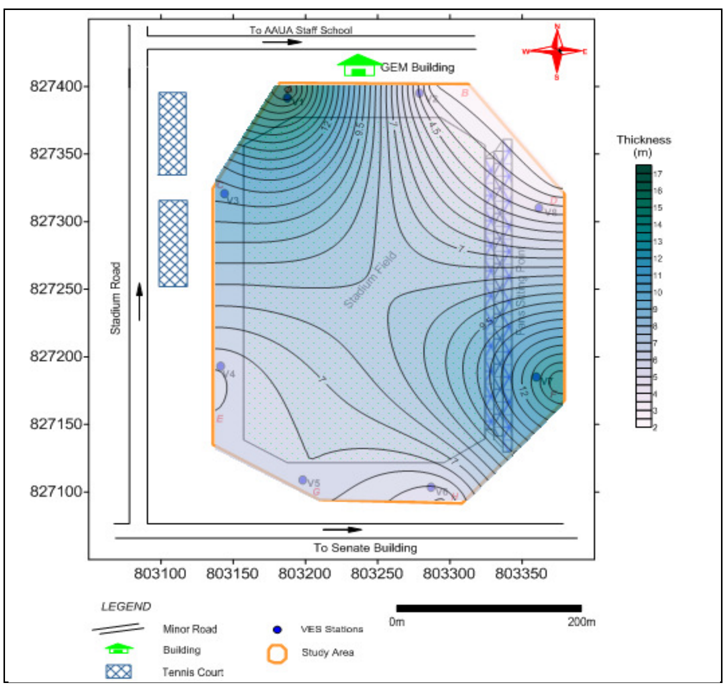

Fig. 7b. Isopach Map of Weathered Layer of the Study Area.

low (< 200 Ωm) and it is observed in VES 1, and 5 of the study area. The map shows the largest thickness in the northwestern part (VES 1) of the study area with thickness up to 17 m while the thickness of the weathered layer varies from 2.2 to 16.7 m. The isopach map shows that the weathered layer is fairly thin (<7 m) and may be absent in some places (as confirmed by the geoelectric section). Nevertheless, it shows fairly to highly thick weathered layer (>8 m) from the ESE-NWN within the area especially for VES stations 1, 3, and 7.The resistivity is moderately high (250-600 Ωm) in the west and eastern portion of the area. The low and moderately high resistivities may be indicated as aquiferous zones that are less competent. The higher resistivity depicts competent and compact geologic materials.

Very low resistivity suggests clay materials or water saturated materials, often less competent to support the stability of heavy engineering structures. The depth of the aquifer units ranges between 1.2 m and 8 m in the area. An important factor often considered in foundation design is the water table and water table fluctuation (Bowles, 1984; Coduto, 1998). In addition, raised water table may create a wet basement or foundation, and consequently engenders instability of the overlying structure (Bowles, 1984; Othman, 2007).

Conclusion

It was deduced from the results of the Vertical Electrical Sounding that the area is characterized by H, HA, AA, and KH curve types, with the KH-type predominant. Three to four geoelectric layers were delineated within the study area which includes: the topsoil, the weathered layer (gneissic rocks), fractured basement and the fresh basement rock (Granite gneiss). The resistivity of the topsoil reveals that its composition varies from clay to laterite, while the other layers are weathered, fractured or weathered/fractured basement and fresh basement.

The generated maps obtained from the geoelectric parameters revealed the variation of the different layer resistivity and thicknesses within the area. The study revealed that the resistivity ranged between 20 and 900 Ωm and overburden which range between 0.5 and

17 m (enhanced by the fracturing of the basement). The depth of the partially competent bed ranged from 20.5 – 33.9 m.

The first and second layers are highly saturated at the northern (VES 1 and 2) and southern (VES 5 and 6) parts of the study area, and it is rated incompetent. Ground treatment such as dewatering and in-situ compaction (soil stabilization) should precede the use of reinforced concrete during the construction of both shallow and deep foundations because the underlying geologic constituents are less competent for engineering structures but VES 1 that has a very deep depth of about 20 m to the basement would require pilling foundation.

VES 3, 4 and 7 have intermediate to very high resistivity values and rated competent. VES 3 has the highest resistivity but underlain by fractured basement, but could be considered for structures having less weight with shallow foundation to considerable depth.

Based on the information above depending on the size of structures to be erected, it is recommended that if shallow foundation were to be employed for construction then the concrete must be reinforced. The use of piling may be necessary for massive structures to rest directly on competent materials.
Few boreholes are recommended for sampling and testing of geotechnical properties.

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